LUBRICATION

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Plain Bearing Lubricating Systems

BEARING design has been a fascinating study ever since Isaac Babbitt made the bearing metal which has borne his name for over a hundred years. It is probable that the age of steam would have progressed far more slowly if machinery builders had not been able to get away from using brass and iron for bearing purposes. Most certainly electricity and the internal combustion engine would have been only possibilities. But, Babbitt's alloy of copper, tin and antimony paved the way to a new era in machine design, just as some of the later alloys, which include cadmium and silver, have promoted the perfection of the modern high speed automotive and aircraft engine.

Along with this development of bearing metals came certain transitions in lubrication, lubricating systems and methods of lubricant manufacture. Their combined influence upon machine design has culminated in the perfection of the modern steam turbine, the high speed internal combustion engine and innumerable applications of the sleeve bearing to industrial machinery.

As bearing metal alloys of higher and higher unit load carrying capacity were developed and methods of positive lubrication were applied, noticeably lower clearances were permitted. This led to study of oil films verging on boundary lubrication. It opened up a new field of research for the petroleum chemist, in his efforts to produce lubricants of minimum power consumption.

BEARING DESIGN

Sleeve type bearings constitute the supporting or carrying elements for shafting, journals, rods or pins in a wide variety of machinery. As such they are subjected to the sliding or rotating motion of these parts. This presents the possibility of metal-to-metal contact. Obviously, actual metallic contact would lead to serious difficulties due to friction, abnormal rise in temperature, and the subsequent possibility of softening or even melting of the bearing metal; this would cause the shaft or other moving element to drop or seize. It is prevented and continued operation is assured by maintenance of a film of lubricant within the clearance space between the surfaces of the bearing and its component moving part. This amounts to substitution of fluid friction for solid friction. With the former, the frictional loss is low, though it depends upon the viscosity of the oil.

In laboratory research, viscosity is the predominating characteristic. In service, however, it is necessary to look beyond this strictly physical property, and investigate the stability and the resistance to breakdown, oxidation and emulsification. These factors are most important when an oil is to be subjected to heavy duty service, moisture contact and heat. In plain or sleeve type bearings, composition of bearing metals, bearing grooving and methods of lubrication are also functions of effective lubrication. The objective is assured by positive and continuous delivery of the necessary amount of lubricant to maintain the lubricating film, and by bearing construction which will permit of complete circulation of the lubricant through the clearance space.

The steam turbine, Diesel and automotive engine, the reciprocating steam engine and a wide variety of industrial machinery ranging from the high speed grinding machine spindle to the massive mirror-finish steel mill roll neck

bearing are typical of applications of the sleeve bearing and the principles of fluid film lubrication. With continued improvement in methods of lubrication this design is becoming even more marked changes in conventional design, which in turn have assisted in speeding up machine operations and reducing vibrations by facilitating the use of lower viscosity oils. The

Courtesy of Ingersoll-Rand Company

Fig. 1—Main bearing construction on an I-R class PRE compressor. Note removable and adjusting features. Automatic oil lubrication is provided for protection in service.

firmly established as an adjunct to dependable operation of equipment to which it can be applied.

This is further enhanced by study of bearing design in order to assure of proper location of oil grooves and to develop the proper angle of bevel or chamfer at bearing joints or breaks in the bearing surface. No bearing should be cut away or have the continuity of its surface altered by grooves within thirty degrees either way of the point of maximum pressure; otherwise uniformity in the oil film may be impaired. In some bearings it may even be advisable to increase this figure materially, according to clearance and speed conditions. The lubricant in turn, should be fed to the bearing at the point where pressure is lowest and where wedge action via chamfering will be properly developed so that a continuous film will be maintained.

As the theory of lubrication has become clarified it has indicated that a definite relation exists between load, operating speed, bearing clearance, viscosity of the lubricant and point of application. The theory of lubrication has long been a popular subject for research and discussion among scientists who have interested themselves in oil film development and behavior. Their investigations have led to steam turbine and grinding machine spindle are notable examples.

Most recently these studies have been directed towards adaptation of accepted theories to practical solution of problems which are of direct interest to designing and operating engineers. This research has indicated the practicability of checking theory against practice, viz., by checking calculated viscosity against the actual viscosity of an oil the characteristics of which have been previously indicated by operating experience. In this way correction can be made for any error unconsciously made in deciding upon the initial viscosity of the oil. Thus a product best suited to the operating conditions can be obtained, capable of developing the lowest coefficient of friction for the existing speed, load and clearance conditions.

There is, of course, a direct relation between these factors and bearing construction. Bearing metals in particular must be thoroughly understood, for the combination of bearing metal plus lubrication may readily determine whether a machine will operate successfully or not. When lubrication is effective and an adequate film is constantly maintained, the bearing serves chiefly as a guide to insure alignment. Should

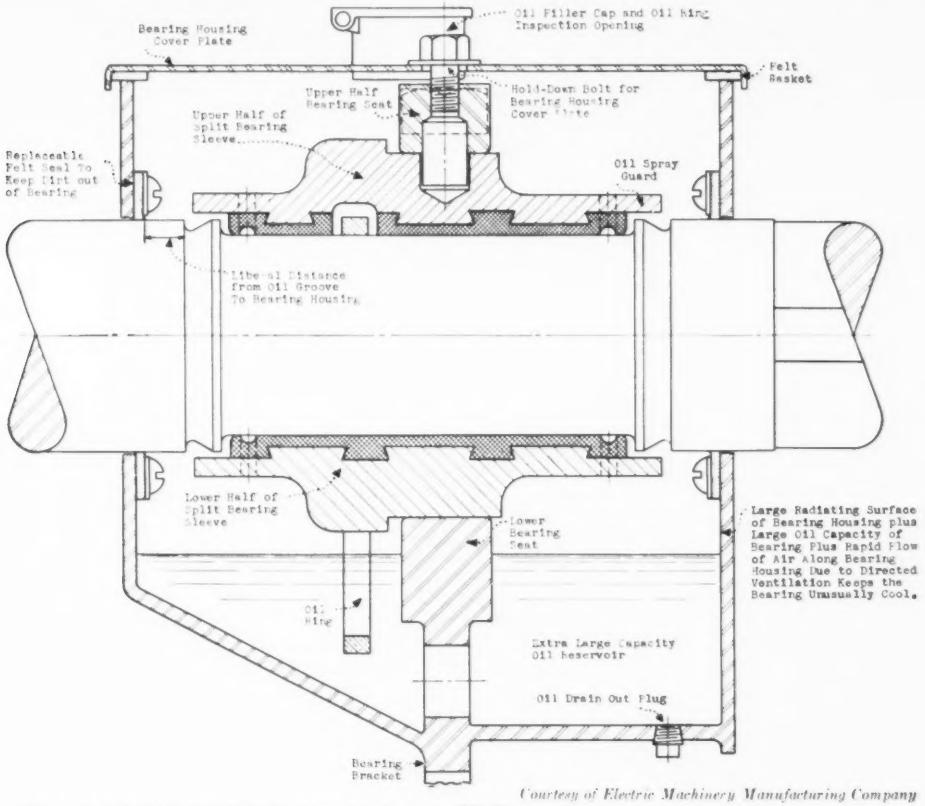
the lubricating film fail, it devolves upon the bearing to function as a safeguard to prevent actual damage to shafting or other parts of the machine. This might easily become very costly on a unit such as a steam turbine where damage to the blades might occur.

Bearing metals are softer than any of the steels used for shafting or journal construction. They are also designed to be sufficiently plastic or ductile so as to conform with any irregularities on the surface of the shaft. This insures that in case of overheating there will be less possibility of scoring or cutting of the more expensive steel. Under such conditions the bearing metal will wipe or even melt. The utmost protection of the rotating or sliding elements is assured when the bearing metal has a low coefficient of friction, with ability to assist in the maintenance of the lubricating film, yet bearing metals must be sufficientiy hard to carry the prevailing loads, even at abnormally high temperatures so that they will not wipe or become prematurely distorted.

which a bearing can be expected to function effectively in service will depend upon its initial formation, including the manner in which it has been poured or cast, the temperature of pouring and the precautions observed in pre-heating the shell or mould. The pouring temperature will be contingent upon the type of bearing metal, its base and the relative percentages of the metals which comprise the alloy. Average pouring temperatures for babbitts will range from 600 to 900 degrees Fahr. Bronzes and specialty bearing materials must be poured at higher temperatures.

Alignment

Alignment is a most important factor in the maintenance of efficient plain bearing operation. Any misalignment will immediately lead to abnormal wear, varying in intensity according to what we might term the angle of error. Under such a condition the shaft will not bear uniformly over the bearing surface, but at the ends, with abnormal pressure. This may read-


Oil Filler Cap and Oil Ring Inspection Opening
Bearing Housing Cover Plate
Felt Gasket
Upper Half Bearing Seat
Hold-Down Bolt for Bearing Housing Cover Plate
Upper Half of Split Bearing Sleeve
Replaceable Felt Seal To Keep Dirt out of Bearing
Oil Spray Guard
Liberal Distance from Oil Groove To Bearing Housing
Lower Half of Split Bearing Sleeve
Lower Bearing Seat
Large Radiating Surface of Bearing Housing plus Large Oil Capacity of Bearing Plus Rapid Flow of Air Along Bearing Housing Due to Directed Ventilation Keeps the Bearing Unusually Cool.
Oil Ring
Extra Large Capacity Oil Reservoir
Oil Drain Out Plug
Bearing Bracket

Courtesy of Electric Machinery Manufacturing Company

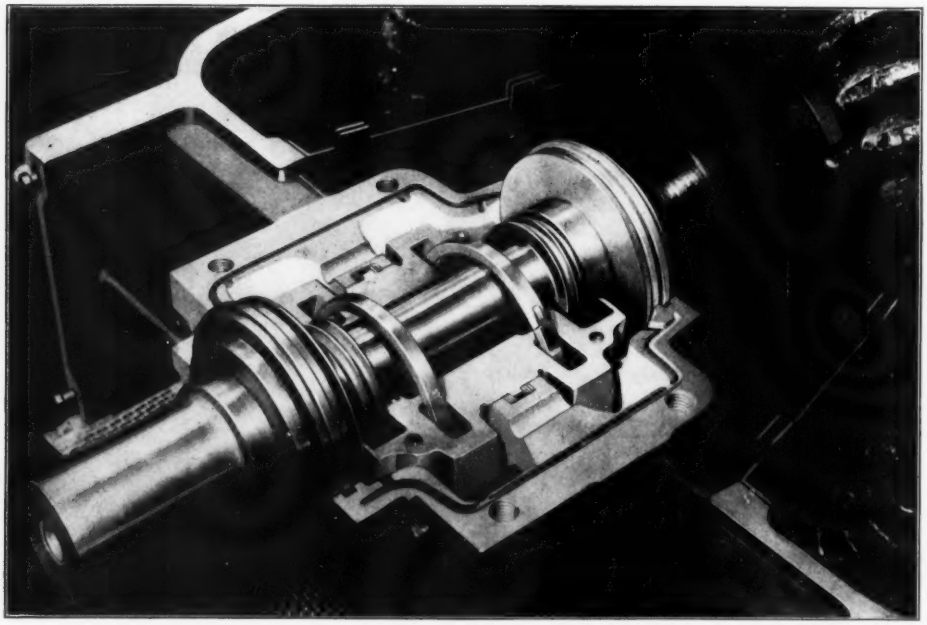
Fig. 2—Details of the ring-oiled, sleeve-type bearing on an EM Motor. Note bearing metal arrangement.

To enable ready handling and proper forming, bearing metals must pour easily and maintain a uniform alloy structure throughout the body of the material. In this regard the extent to

ily lead to excessive wear at these points, overheating and even wiping of the bearing metal.

The longer the bearing with respect to the diameter the greater may this wear become

under even very slight conditions of misalignment. So bearing designers endeavor to reduce the length wherever possible, and approach an L. D. (length to diameter) ratio of around 2 to 1 or even 1 to 1, in some cases. This becomes especially beneficial on power transmission equipment.



Courtesy of Allis-Chalmers Mfg. Co.

Fig. 3—Bearing of a 3600 r.p.m. squirrel cage induction motor. Note air intake screen below the bearing.

OIL GROOVING

When soft metals predominated in bearing design, oil grooving was a generally accepted procedure. This still holds true, for proper grooving is a definite assistant to lubrication of the tin or lead base bearing metals.

With harder bearing alloys, mirror finishes, increase in machine speeds and perfection of flood and pressure oiling systems, oil grooving is regarded as less important. In fact, in automotive and aviation engine design rod and pin bearings may carry no grooving at all on the theory that development of the oil film under constant pressure will maintain this film in conjunction with the natural pumping action which is developed at high speeds. Furthermore, elimination of grooving increases the effective bearing area, permitting reduction of over-all bearing dimensions.

Oil grooves, where necessary, are cut in the low pressure surfaces of the bearing, to aid in developing complete circulation of oil and maintenance of a sufficiently protective film at the high pressure area. They constitute a series of depressions in the bearing surface, connected or so located with respect to each other and the point of maximum bearing pressure as to insure not only complete and ready distribution of lubricant throughout the bearing clearance, but also a pathway for collection and subsequent removal of any non-lubricating material which might otherwise interfere with free flow of the oil film.

Not infrequently too little importance is attached to oil-grooving in bearings where it should be applied. Some have even felt that it was only necessary to drill an oil hole or two and that the film would spread by some magical means. This is literally true in the precision bearing designed for circulated flood lubrication, but it is certainly not to be depended upon in rough service bearings where an oil cup or compression grease cup may be the means of lubrication. The rotating shaft always develops some pumping action to draw lubricant into the clearance, but unless wedge formation is facilitated by chamfering at the point of oil inlet, this action may be very slight. Then we may approach boundary lubrication, but unfortunately in a type of bearing which is not designed for thin oil film protection. Hot running bearings with increase in power consumption and ultimate wiping of the bearing metal are indications of such a condition.

So bearing oil grooves should not be just cut to a pattern to suit individual fancy. Some

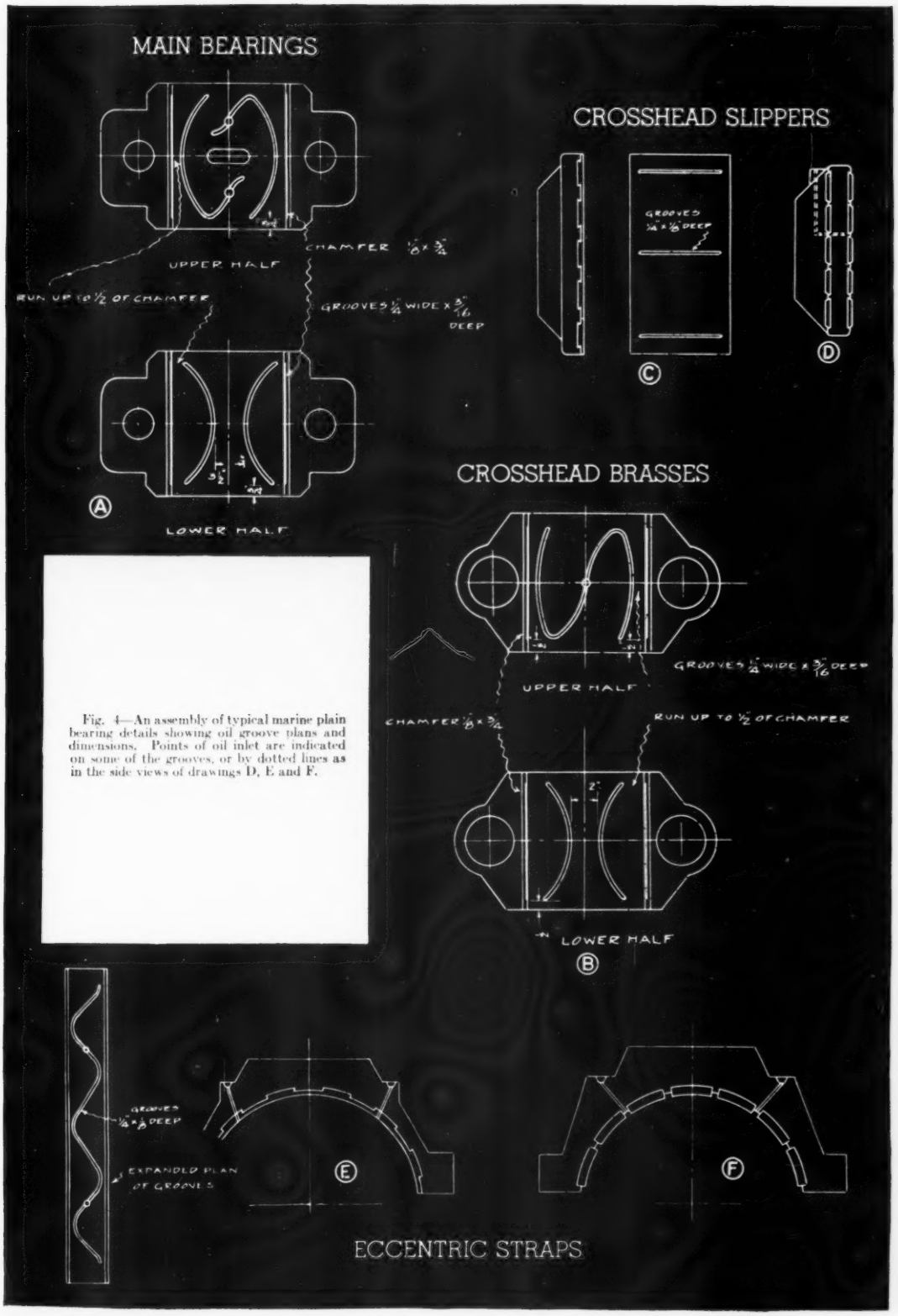
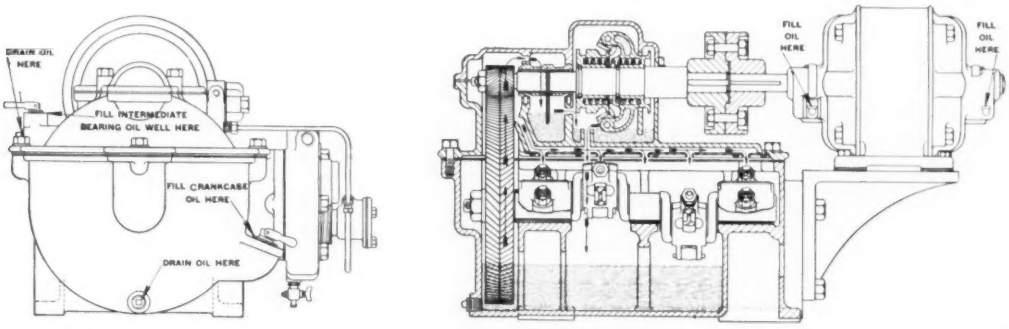


Fig. 4—An assembly of typical marine plain bearing details showing oil groove plans and dimensions. Points of oil inlet are indicated on some of the grooves, or by dotted lines as in the side views of drawings D, E and F.

definite designs have been applied so successfully in practice as to render them virtually standard. Then they can best serve as a means of distributing lubricant lengthwise along the bearing so that the clearance is uniformly filled. The lubricating film is maintained by rotation or sliding of the moving element developing the necessary pumping action. The groove is merely an inlet receptacle for receiving and distributing the lubricant. Where properly designed the groove can also aid in keeping lubricant within the clearance, preventing excessive leakage at the ends of the bearing. Such a design facilitates circulation of the oil alternately from the center to the outer ends of the bearing and back again. How intricate to make the grooving design would depend upon the means of lubrication. With periodic lubrication involving sight or drip feed oil cups, oil grooving and oil retention is more important than where flood lubrication and oil circulation is available.



Courtesy of Westinghouse Air Brake Company

Fig. 5—Details of the Westinghouse air brake "NWB" motor driven compressor showing oil filler fittings and oil drains. Arrows indicate circulation of oil via the gears and ring-oiled plain bearing, etc.

Planning the Grooves

Oil grooving is most effectual where it is of comparatively simple design and devoid of sharp curves. The more usual plans as shown in Figure 4 have been developed through practical experience and probably many thousands of hours in engine, compressor or shaft service. Any or all might function effectively under similar operating conditions, provided the lubricating system is dependable. The all-important factor is to develop lubrication to such a degree that friction and power consumption will be reduced to the minimum. The means employed is more or less secondary, although the effective bearing area must not be reduced by too extensive grooving. In other words, grooving should only be applied to those bearing areas which are in the low pressure zone. In a two-part bearing this will mean that only the top should be grooved. In a four-part bearing the segments to consider would depend upon the direction of rotation of the journal or shaft. Normally the bottom part should be plain or ungrooved.

The purpose, of course, is to be in accord with the theory of lubrication which dictates that oil must flow from a low pressure area to a zone of higher pressure. Grooving of this latter might result in the grooves becoming runways to lead oil away from the clearance. Ultimately starved lubrication and actual metallic contact might occur, especially under high load conditions. Oil leakage at bearing ends is often an indication of faulty grooving or grooving extending into the high pressure area, especially if bearing temperatures increase at the same time.

Cutting or Formation

Having decided upon the bearing area which should be grooved and the types of grooves to use, it is then advisable to make a rough calculation of the dimensions. These will depend upon the diameter of the shaft or journal which is to be carried by the bearing.

The width of a groove is calculated by multiplying the diameter in inches by 0.01 and adding 0.10 of an inch as a factor of safety.

The depth of the groove is taken as one-half the calculated width.

An oil groove should never be extended too close to the end of a bearing surface, otherwise a channel might be provided which would allow the oil to escape from the bearing clearance to be prematurely lost by drip or leakage. The approximate distance a groove should be kept in from the bearing edge varies according to the diameter. The following table is of interest in this connection:

Bearing diameter	Distance of oil groove from either end
$1\frac{3}{4}$″ or less	$\frac{1}{4}$″ minimum
$1\frac{3}{4}$″ to 2″	$\frac{3}{8}$″
2″ to 6″	$\frac{1}{2}$″
6″ and larger	1″

Bearing Metal Thickness

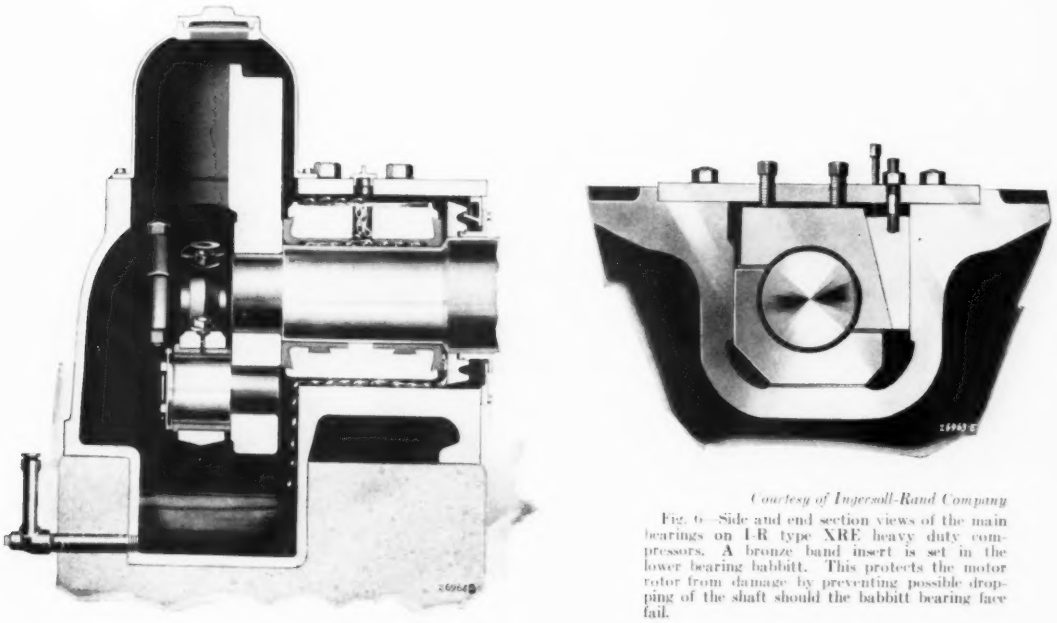
It is obvious that the bearing metal should always be thick enough to allow for the calculated depth of groove without danger of cutting through to the bearing shell. So it is always advisable to note the approximate thickness of bearing metal available before the grooves are cut or the edges chamfered.

It is also important to remember that when planning a system of oil grooving and calculating the dimensions, the available bearing area is reduced by these grooves. Under normal conditions, where they are cut in the top half or low pressure area actual metal-to-metal contact may not be as likely as in the high pressure area where the load is carried. But as some pressure is carried over the entire bearing especially under higher speed conditions, even the low pressure area should not be reduced any more than necessary by excessive grooving.

The actual cutting of an oil groove must be done with the utmost care, in order that the finished groove may conform as closely as possible with the calculated dimensions and the intended location with respect to the curvature and length of the bearing. Uneven cutting or irregular edges may lead to clogging if non-lubricating material gains entry. In this connection we must remember that more or less non-lubricating solid foreign matter such as dirt or metallic particles will be present in almost any oil after service for any length of time. Furthermore, if higher operating temperatures prevail, certain types of lubricants may have a tendency to breakdown and form gummy or carbon-like deposits. As material of this nature is also more or less inert, it will reduce the circulating ability of an oil, and accumulate at high spots in the oil grooves to serve as a dam and further impede free and complete circulation of the lubricant. Once begun, oil or grease breakdown and accumulation of non-lubricating deposits is often cumulative to such an extent that ultimately bearing failure will result through starved lubrication at the pressure area.

Oil grooves can be cut by hand or by machine. With hand cutting there may be possibility of some variation from the calculated dimensions, although the fineness of the work will depend upon the skill of the mechanic and the care in handling the cutting tools. Rough surfaces must be eliminated regardless of the method of cutting, for as already indicated, rough spots will not only impede free oil circulation, but they may also act as catch-alls for non-lubricating foreign matter.

Roughness in an oil groove may be indicated by loose particles of bearing metal. If adjacent to the main surface of the bearing the occurrence of metal-to-metal contact might lead to breaking or chipping off of certain of these metallic particles, to cause contamination of the lubricant and possible scoring of the shaft or bearing surface, especially where bearing alloys containing a considerable amount of harder metals are involved.

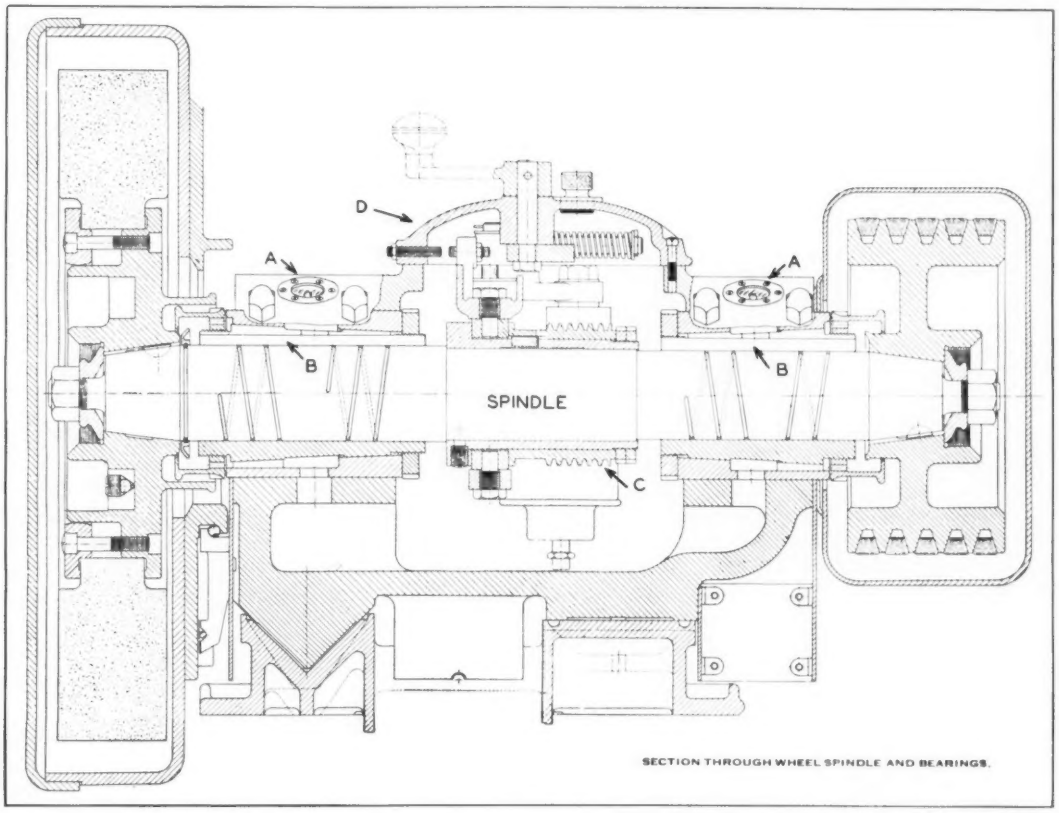


Courtesy of Ingersoll-Rand Company

Fig. 6—Side and end section views of the main bearings on I-R type XRE heavy duty compressors. A bronze band insert is set in the lower bearing babbitt. This protects the motor rotor from damage by preventing possible dropping of the shaft should the babbitt bearing face fail.

THE OIL FILM

Thin oil film lubrication has been a favorite study of research investigators since Osborne Reynolds developed his classic theory. With the realization of fine finishes it became a cannot be operated at full power or production. So the return on the investment does not really begin until all the parts are worn in to a flexible running fit. As this became more fully realized study was made of ways and means to reduce



Courtesy of Norton Company

Fig. 7—Assembly of the Norton grinder wheel spindle unit. This design is unique in that the oil grooves are cut on the spindle or rotating member instead of the bearings. These latter (see B) are of bronze tapered on their outer diameter and drawn into cast iron cases. Lubrication is maintained by a small pump driven by a spiral gear from Worm "C" on the spindle. This pumps spindle lubricant from a reservoir in the wheel slide through an external filter, and thence to each bearing. Flow of lubricant is observed through a sight window "A" above each bearing; it can be regulated by a cock adjacent thereto. The same lubrication system serves the end thrust, the worm drive, and reciprocating parts by direct application through flexible tubing (to the end thrust parts), or by spray deflected from the housing cover "D".

Important factors in the maintenance of low viscosity lubrication are well flushed bearing surfaces, proper bearing adjustment, and provision for taking complete advantage of the cooling ability of the lubricant.

reality. Lower clearances were practicable, controlled pressure was applied to regulate the oil flow. This permitted the use of lower viscosity oils in which internal friction would be less, for heat transfer is an important item. The lower the generated heat the less the load on the oil film.

Surface finish is a most important factor in the development and maintenance of dependable lubrication of the plain bearing. Progress in machine design has been responsible for marked interest in the finishing of surfaces of parts which are subject to motion with respect to one another. There used to be a time when shafts or journals were expected to wear in to a running fit with their respective bearings. During the run-in period, however, the machine the length of the run-in period, or to eliminate it entirely. Better surface finish was the answer; it was made practicable by more careful grinding and polishing, to smooth down those microscopic high spots which would otherwise have to be done in service at the expense of power consumption, reduced productive efficiency and increased load on the lubricant.

Research in the field of fluid and boundary lubrication was definitely allied with this matter of surface finish and the application of thin oil film lubrication to plain or sleeve type bearings. It proved that the effect of friction on power consumption can be materially reduced by improving the smoothness of the metallic surfaces of the moving parts. There were limitations, of course, as some investigators learned

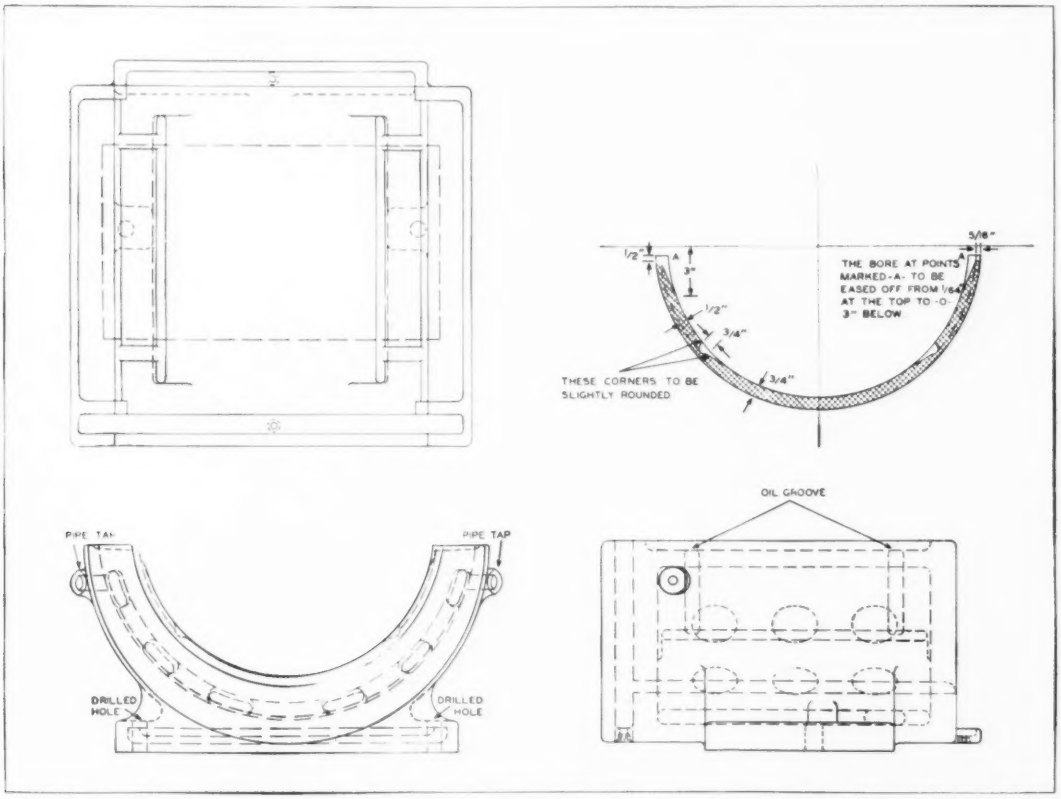
when they carried their polishing operations too far; then it was found advisable to purposely hone or roughen the surfaces in order to facilitate lubrication-service. This developed an approach to boundary lubrication at the apex of the honed depressions.

So perfect finish of a bearing surface is an ideal which should not be approached too closely. The degree of smoothness should be just sufficient to develop the maximum load-carrying capacity. In other words, we should strive to reduce the high spots but not attempt to entirely eliminate the depressions. They provide factors of safety in the form of minutely shallow oil pockets which present a reserve of oil supply to prevent incipient scoring should any abnormal condition develop. Laboratory research has proved that by extremely careful workmanship it is possible to develop a difference in level between the top of a peak and the bottom of a depression or valley of about two-millionths of an inch. Even this minute distance is still over twenty times the length of an average molecule of oil.

ity to circulate the lubricant through the bearing clearance, or by taking advantage of the natural pumping action developed by rotation of the shaft or journal. Induced pressure develops where the bearings are ring-oiled. It is also an adjunct to splash lubrication as typified by the crankcase assembly in a horizontal air compressor.

Induced pressure can only be developed where the bearing is properly grooved and where all sharp edges are eliminated by chamfering to enable wedge formation of the oil film at the point of entry into the clearance. Then the shaft or journal can develop the pumping action which is necessary to induced pressure. Sufficient lubricant must be delivered meanwhile by the ring or chain oiler, by the oil splash mechanism, or by an external lubricator.

Pressure lubrication of the sleeve-type bearing became a reality with the perfection of the steam turbine. When Parsons and De Laval developed their principles of blade design and applied their ideas to the generation of power in stationary service, the necessary



Courtesy of Farrel-Birmingham Company, Inc.

Fig. 8—A 20 inch water-cooled bottom bearing for a paper mill calender. Note oil groove features and details of the chamfer at upper right.

DEVELOPING THE OIL FILM

Pressure lubrication is applied or induced. By this is meant pumping or utilizing gravspeeds required careful attention to design of a lubricating system which would function coincident with the turbine, and insure continuous

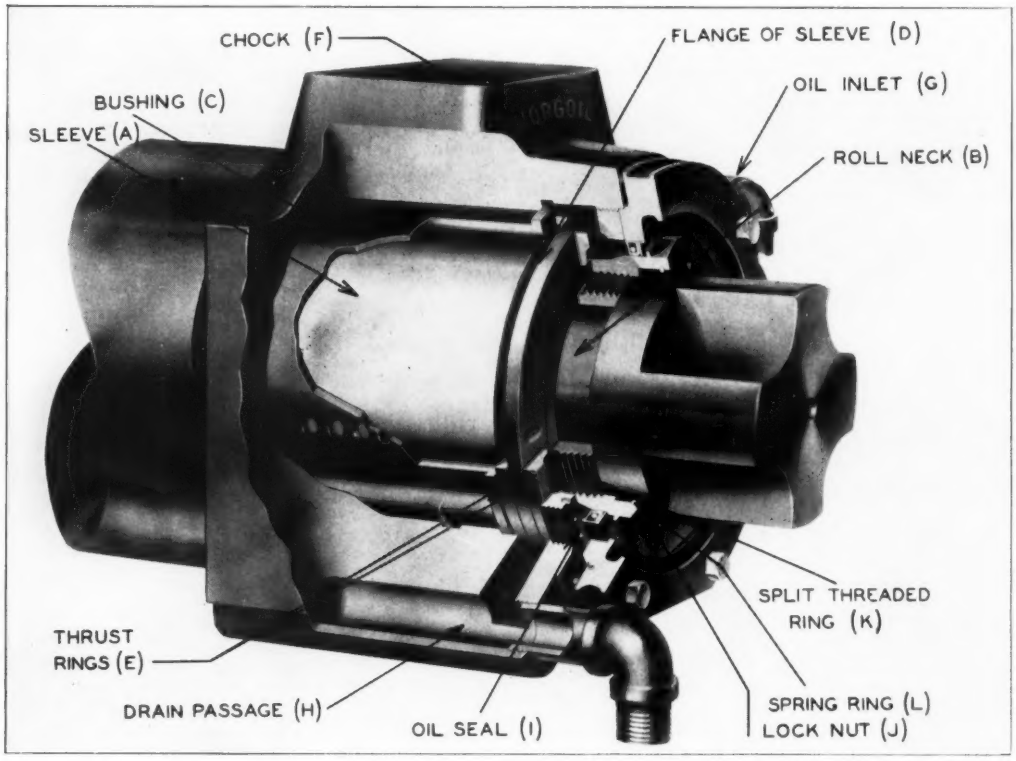
delivery of a generous supply of oil to the bearings. This resulted in the application of two methods of lubricant control, viz.:

By gravity circulation, or
By direct pressure.

rolls and pumping oil through the clearance spaces.

Gravity Distribution

Where a gravity system is employed in tur-



Courtesy of Morgan Construction Company

Fig. 9—The Morgoil roll neck bearing showing details of construction essential to development and maintenance of the oil film.

In some form or other, these are applied to sleeve-type bearings today wherever so-called flood lubrication is desired, though the arrangement of the system may vary widely. Quite naturally, it must be planned according to the service and the operating conditions. Before the development of the high-speed grinder, the governor, and industrial machinery such as the paper mill calender and the mirror-finish steel mill roll neck bearing, oiling systems were considered chiefly from the viewpoint of lubrication; it was only necessary for the oil to be of proper viscosity to afford good lubrication, and to be able to function as a heat transfer medium.

Today, however, the pressure circulating system requires an intricate assembly of gages, alarms, and emergency shut-down devices. In the turbine the oil must also operate the governor, and on the calender stack auxiliary pumping equipment may be necessary to insure lubrication even before starting, by raising the

bine service, gravity is only made use of as an adjunct to oil delivery to the turbine bearings; pumps are necessary for oil return to the purifiers and overhead storage tanks. In other words, the oil must be continually returned to one or more tanks located above the unit, from whence it is allowed to flow by gravity to the bearings.

Thirty feet constitute the usual minimum height at which any gravity tank should be placed above the operating platform level. Under these conditions, the lowest pressure at the bearings will range from 10 to 12 pounds. When the oil has passed through the bearings (and if necessary the gears) and drained into the sump, it is cooled, strained, and subjected to filtration or centrifugal purification, after which it is pumped back to the overhead gravity tank for re-circulation.

The gravity oiling system is dependable in that:

(1) There is a steady, uninterrupted flow of

oil; whereas with the pressure system, the flow may be more or less pulsating where a reciprocating pump is installed.

(2) Due to the oil being returned periodically to an overhead tank, where it is allowed to rest momentarily, any air which may be contained has an opportunity to escape.

(3) It is reliable due to the fact that if the oil pump stops, there will still be a few minutes' supply of stand-by oil in the gravity tank to keep the bearings lubricated until the spare pump can be started, or the main machinery shut down.

The success of a gravity oiling system depends largely on the pipe line from the tank to the equipment being direct, i. e., with the minimum number of bends and of sufficient diameter to insure proper pressure on the system. In other words, the performance of a gravity system depends a good deal upon the manner in which it has been originally installed. The size of a gravity tank may vary from a minimum of about 250 gallons capacity to a maximum of 600 gallons capacity. The total amount of oil in such a system naturally varies with the size of the installation. It is generally somewhat greater than in a pressure system serving the same size unit, as with the latter the gravity or reserve tank is eliminated.

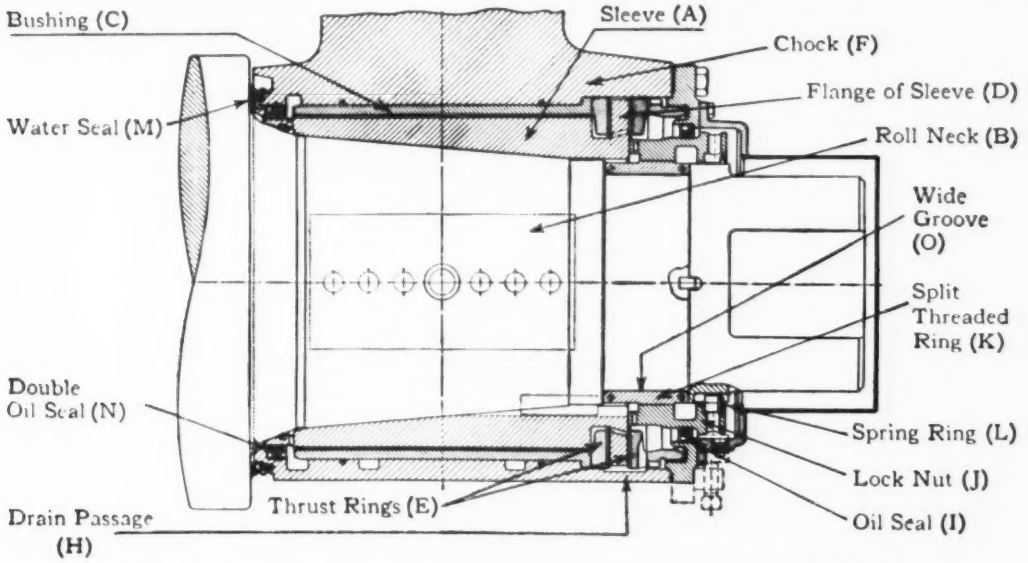
to install than a gravity system, since less equipment is required. In its operation the lubricating oil pumps draw the oil from the sump, drain tank, or purifying system through coolers, etc., as in the gravity system, and apply it to the unit bearings under pressure. No reserve tank is provided and as the oil drains back to the sump tank, it is again picked up by the pumps and the cycle repeated.

Any direct pressure system must be of ample size in order that the circulation of oil will not be too rapid. Where units are operating with too small a quantity of oil in the system, the circulation of this latter may be so rapid that there is but little time for it to settle and cool. Under such conditions, not only may the bearings suffer, but also the oil may break down more readily.

A pressure system should always deliver oil to the bearings in excess of that required, a relief valve or other means being provided to drain the excess oil back to the sump tank. An advantage of the direct pressure system is that it is possible to obtain practically any desired pressure on the bearings merely by regulating the oil pump.

THE LUBRICANTS

It was obvious that these mechanical perfections required lubricating oils of greater stability, resistance to oxidation, and devoid of acid-



Courtesy of Morgan Construction Company

Fig. 10. Another view of the Morgoil bearing, in section, showing the seal construction which is so essential in protecting the lubricant from contamination.

Direct Pressure System

Continuous circulation of oil by a direct pressure lubricating system likewise has its advocates and advantages. It is often cheaper

forming constituents which might corrode the bearings. This presented a problem for the petroleum research chemist. His duty was to study available crude oils as to the types of

lubricating fractions which could be produced by improved refinery methods. Fortunately he was assisted by prior research into the effect of a variety of materials in removing certain petroleum hydrocarbons which are known to be the basic components of sludges which develop when oils containing these hydrocarbons are subjected to oxidizing conditions.

Refinery Procedure

Solvent refining involves contacting the oil to be refined with a solvent which is able to selectively remove certain types of hydrocarbons and which at the same time has no adverse effect on the desirable constituents. The process is purely a physical separation and no chemical reaction occurs during the counterflow contact of the materials. In most solvent refining processes the undesirable hydrocarbons go into solution while the desirable constituents remain out of solution. This results in a two-phase system with the refined oil (plus a small amount of solvent) as one phase, and solvent plus the dissolved hydrocarbons which are to be removed as the other phase. The solvent has a much higher specific gravity than the oil so that the two phases are readily separated by gravity settling.

Several solvents have been developed for refining purposes such as sulfur dioxide, furfural, nitro benzene, phenol and chlorex. Although any one of these solvents may be used, they do not all remove the same type of compounds to the same degree, and the refiner must adjust his subsequent processing accordingly. All, however, can be recovered by distillation for reusage.

Another common method of removing certain types of undesirable constituents is treatment with acid. Acid treatment, which may be used as an adjunct to solvent refining, differs from the latter in that the sulfuric acid used reacts chemically with certain of the hydrocarbons, whereas solvent refining effects purely physical separation. Acid treatment may be either a batch or continuous operation, the latter requiring the use of centrifuges for continuous removal of the acid sludge.

In these processes the oil and acid are thoroughly mixed in the desired proportion and the sludge and acid are then separated either by gravity settling or by centrifuging. The oil layer is then washed with water and any remaining acidic materials are neutralized by suitable chemical treatment.

Final treatment of oils for circulating systems requiring turbine grade quality, is accomplished by percolating the oil through a bed of fullers earth. This is a natural adsorptive clay that has the property of being able to adsorb coloring bodies and small traces of soaps from an oil. The oil is slowly pumped through the clay bed at relatively low temperatures in the neighborhood of 100 to 150 degrees Fahr., depending upon the viscosity of the oil.

Turbine and Steel Mill Roll Neck Bearings

The petroleum chemist has also learned the value of measuring the chemical stability of lubricating oils in terms of their resistance to oxidation. In this he is able to accelerate operating conditions of pressure, temperature, moisture and air as they may prevail in actual service in the turbine room or steel mill. The chemist attains his object in an atmosphere of oxygen or by use of a pressure bomb.

The remarkable records which are available in virtually any steam turbine power plant today are a tribute to the ability of the oil refiner to meet the prevailing pressure and temperature condition. These same types of oils of higher viscosity have more recently been applied to lubricating the pressure-oiled sleeve type, steel mill roll neck bearing with equal success and every indication that like durability will signalize their performance in this even more intensive type of service.

Engine Service

Lubricating oils for airplane and Diesel engines must also be more stable and less readily affected by heat than ever before. The petroleum chemist has learned that the stability of such an oil may depend as much upon the operating conditions as upon the structure of the oil. Metals as well as oxygen, are important factors in the deterioration of such oils. Copper has long been known to be objectionable in this regard. More recently research has proved that iron in certain forms is quite active in bringing about deterioration of oils unless the latter are suitably prepared. This meant that the oil industry had to study the effect of metals upon an oil film when sliding pressure is applied. The value of additives, to increase the load-carrying capacity of an oil film, and prevent failures in certain types of mechanisms when dealing with special bearing metals was also investigated. Some additives by reason of their oiliness or ability to combine with steel, form an auxiliary lubricating film over which the oil molecules can roll. The problem, however, has been to insure that the additive does not form corrosive bodies or other undesirable compounds under extremes of temperature.

Another type of additive which has been considered is the so-called "detergent." This acts to keep any carbon which may be formed by fuel blow-by or lubricating oil breakdown in a dispersed colloidal form which can be drained out at intervals, to prevent stuck rings or valves, or clogging of oil grooves.

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